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Surface Circulation in the Northwestern Gulf of Mexico as Deduced From Drift Bottles

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Surface Circulation in the Northwestern Gulf of Mexico as Deduced From Drift Bottles¹

ROBERT F. TEMPLE and JOHN A. MARTIN²

ABSTRACT

Drift bottles were released monthly at predetermined stations in the northwestern Gulf of Mexico from February 1962 to December 1963. Of the total 7,863 bottles released, 12% (953) were recovered within 30 days after release. Analysis of the monthly recoveries revealed seasonal shifts in the flow of surface waters. Between September and February the dominant flow was west along the Louisiana and east Texas coasts, shifting southwest along the southern Texas coast. Between March and May, currents underwent a transitional period, shifting to the north and onshore, particularly along the south and central Texas coast. Converging currents, also apparent along the south Texas coast, appeared to progress up the coast with time. In June and July the surface flow was to the northeast and east. August was another transitional period with currents appearing to weaken and turning onshore. Movements of surface waters appeared directly related to prevailing winds.

INTRODUCTION

As part of an expanded research effort in 1962 (Kutkuhn 1963), the Bureau of Commercial Fisheries, now the National Marine Fisheries Service, NOAA, initiated a drift bottle study to determine the direction and rate of flow of surface waters in the northwestern Gulf of Mexico. The objectives of this study were: 1) to document on a monthly basis surface current direction and velocity; and 2) to attempt to relate monthly variations in current direction and speed with the success or failures of the yearly shrimp crops. Shrimp are planktonic, and may be dependent upon currents for transportation to the estuarine nursery grounds, which are essential for successful completion of their life cycle. The drift bottle study reported herein began in 1962 and continued through 1963.

Seasonal difference in direction and speed of surface currents in the Gulf of Mexico have been generally described by Smith et al. (1951), Leipper (1954), Curray (1960), Chew et al. (1962), and Ichiye (1962). More recent works on current include those by Drennan (1963), Drennan et al. (1963), Armstrong et al. (1967), Watson and Behrens (1970), Ichiye and Sudo (1971),³ and Moore (1973). Many of the above studies, however, although contributing to an understanding of ocean currents in the Gulf, were restricted to limited geographic areas and completed over relatively short time periods. The data presented in this report are unique in that they were generated from the entire northwestern Gulf of Mexico

and on a monthly basis for a 2-yr period, thus providing a time series heretofore unavailable.

METHODS

Cruises were conducted monthly with chartered shrimp vessels from February 1962 to November 1963 to stations located over the continental shelf (Fig. 1). The monthly schedule was followed as closely as possible, the only exceptions being due to adverse weather conditions or mechanical breakdowns. Operations were similar between years except that fewer stations were occupied in 1963, and one vessel was used to cover the entire study area rather than two as in 1962. The general overall effects of these modifications were that in 1963 the areal coverage was slightly reduced, and the time required to provide total coverage of the study area was increased. The latter effect explains seeming discrepancies in the date labeling of figures used in the analysis to follow. For example, the April cruise in 1963 extended into May.

Drift bottles used throughout the study were made of clear glass, about 22 cm in height, 6 cm in diameter, and had a capacity of about 240 cm³. Each bottle contained a bright reddish-orange card on which was a brief message in Spanish and English. A reward of 50 cents was paid for the return of the card with information of location and date of recovery. In most cases, half the bottles released at a station were ballasted (odd numbers) and half were unballasted (even numbers). Those ballasted floated at or just under the surface. The reason for the use of the two types of bottles was an attempt to determine the direct effects of winds.

The number of bottles released during each cruise varied during the 2-yr study. Generally, 12 bottles were released at each station in 1962; 4-10 bottles were released per station in 1963. This modification did not affect the rate of recovery for bottles within 30 days after release for the percent recovered in 1963 was greater than

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³Ichiye, T., and H. Sudo. 1971. Mixing processes between shelf and deep sea waters of the Texas coast. Dep. Oceanogr., Texas A&M University, Ref. 71-19-T, p. 30.

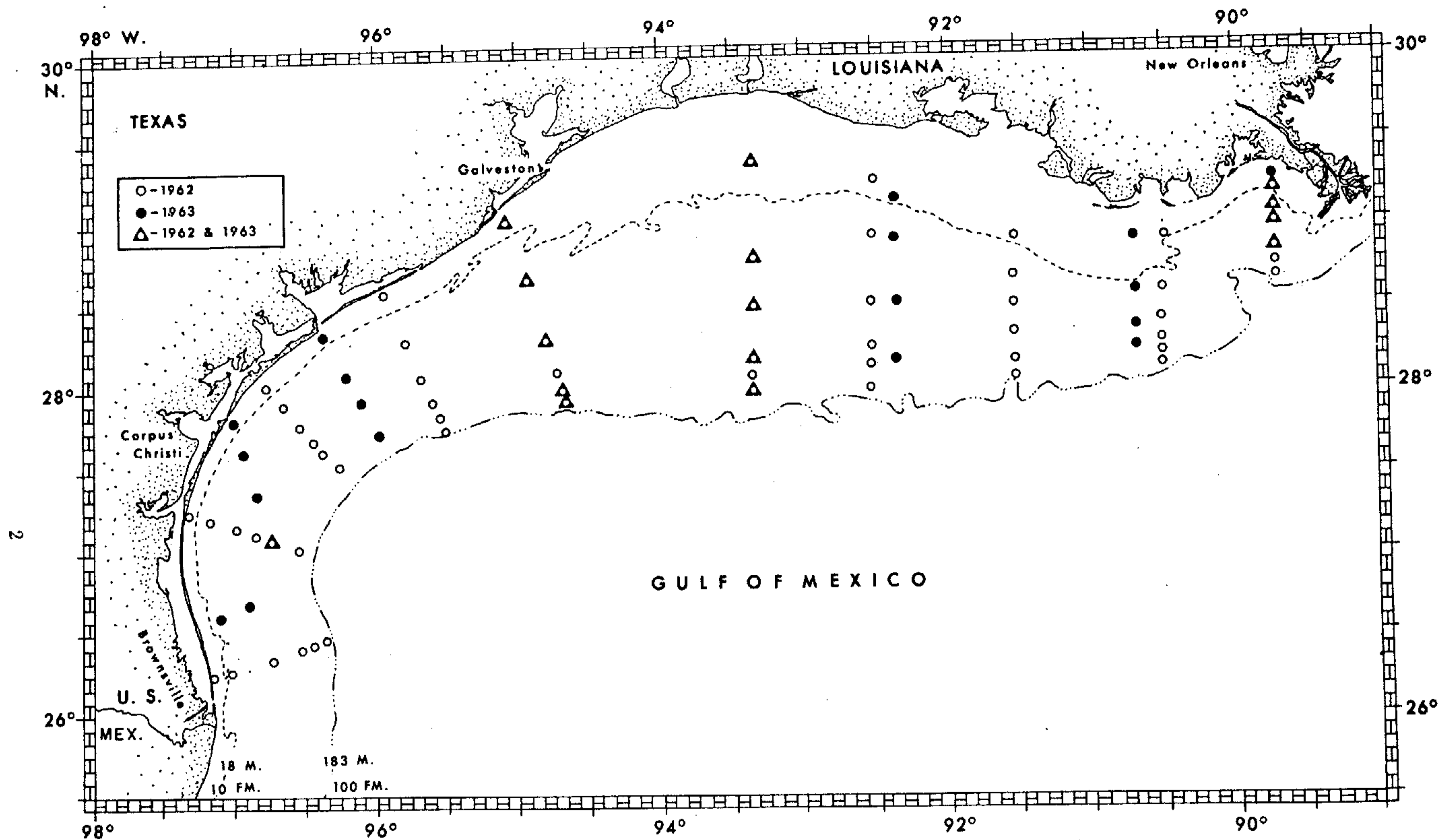


Figure 1.—The drift bottle study area in the northwestern Gulf of Mexico with the location of stations occupied in 1962 and 1963.

in 1962 (Table 1). This increase was probably due to greater public awareness of the program in 1963 than in 1962.

The technique used to depict surface currents was the same as used by Day (1958). Recovered bottles were grouped into two time periods of 15 days each, i.e., 0-15 days and 16-30 days. The 0-15 day recoveries were first plotted as straight lines connecting points of release and recovery. These lines were resolved into directional arrows, and over these arrows we then plotted, as straight lines, the 16-30 day recoveries. The final step was to reduce the 16-30 day straight lines to flow arrows conforming with the 0-15 directional arrows, thus depicting residual drift, not the actual path traversed by a bottle. The reason for the selected groupings and the exclusion of bottles recovered after 30 days was the existence of the sand or sand-shell beaches throughout the northwestern Gulf of Mexico, and the possibility of bottles drifting ashore, remaining intact, but not being found until some later date.

Rates of drift, kilometers per day, were determined from recoveries made within 15 days after release. In instances where several bottles were returned from a single station, the bottle or bottles adrift for the shortest time period were used to determine rate of drift. Also, if two or

more bottles, recovered from the same release, were adrift for the same period of time but had traveled different distances, these distances were averaged before determination of drift rate. Consequently, one directional arrow may represent the recovery of several bottles, and the speed an average speed.

Daily wind data from the climatological records published monthly by the U.S. Weather Bureau, now the National Weather Service, were used to depict prevailing wind conditions over the study area during each cruise (U.S. Department of Commerce 1962-1963a, 1962-1963b, 1962-1963c). This information was recorded at weather stations in Brownsville and Galveston, Tex., and New Orleans, La. Since the time required to complete each cruise varied, it was arbitrarily decided to construct resultant wind vectors for the time period between the first and last days of each cruise plus an additional 15 consecutive days. These data were converted to Beaufort units and incorporated into progressive vector analysis, the lengths of which measured in Beaufort units were divided by the total number of days to give a vector average for each period under consideration.

All drift bottle release and recovery data used in this report are on file in the National Oceanographic Data Center, Department of Commerce, Washington, D.C. 20235, under Ref. 78-0035.

Table 1.—Numbers of drift bottles released and recovered in the Gulf of Mexico within 0-15 and 16-30 days, by cruises, 1962 and 1963.

Cruise	Inclusive Dates	Total Deposited	Recoveries		% Recovered Within 30 days
			0-15	16-30	
1-62	Feb. 17-Feb. 27	651	25	12	6
2-62	Mar. 20-Mar. 27	697	27	53	11
3-62	Apr. 18-Apr. 26	690	33	39	10
4-62	May 18-May 22	525	26	11	7
5-62	June 18-July 1	691	32	25	8
6-62	July 18-Aug. 1	276	21	10	11
7-62	Sep. 7-Sep. 25	663	45	26	11
8-62	Oct. 16-Oct. 30	594	13	8	4
9-62	Nov. 14-Dec. 5	697	74	19	13
10-62	Dec. 4-Dec. 19	583	30	1	5
1962 Totals		6,067	326	204	9
1-63	Jan. 22-Feb. 5	305	13	5	6
2-63	Feb. 19-Mar. 9	203	14	20	17
3-63	Mar. 27-Apr. 6	254	21	61	32
4-63	Apr. 21-May 7	180	46	24	39
5-63	May 13-May 23	209	57	21	37
6-63	June 19-June 27	192	25	31	29
7-63	July 10-July 16	50	1	1	4
8-63	Aug. 17-Aug. 31	118	9	6	13
9-63	Sep. 22-Oct. 4	86	10	35	42
10-63	Oct. 20-Nov 4	111	0	13	12
11-63	Nov. 20-Dec. 1	88	1	9	11
1963 Totals		1,796	197	226	24

RESULTS AND DISCUSSION

Comparison of Ballasted and Unballasted Drift Bottles

Because of the use of two types of bottles, i.e., ballasted and unballasted, data were grouped by bottle type to determine if differences existed between rates of recovery (Table 2), direction of drift, and speed of drift.

Cruise values of percent recovery fluctuated from 22 to 54% between Cruise 1-62 and Cruise 6-63. Thereafter, values fluctuated from 0 to 76%, reflecting probably the reduced number of bottles released during this period (Table 1). It was readily apparent that in general fewer ballasted than unballasted bottles were recovered within 30 days after release (Table 2). For a comparison of direction and speed of ballasted and unballasted bottle drift, we arbitrarily selected 10 "test groups" for analysis, i.e., stations from which several ballasted and unballasted bottles were recovered within 15 days from a single release (Table 3).

The average direction of both types of bottles was usually similar. One exception was "test 8" in which several ballasted bottles moved southward down the coast, while several unballasted bottles moved northward up the coast. Average speeds were also generally

similar with no definite indication that unballasted bottles drifted at a greater rate than did unballasted bottles.

Surface Circulation

Over the 2-yr period, surface currents underwent distinct directional shifts which were, in general, similar between years. Because of this, specific months, although illustrated individually, have been grouped, irrespective of years: January-February; March-May; June-July; August; and September-December.

January-February.—Currents during this period generally paralleled the northwestern Gulf coast, flowing west off Louisiana and becoming southwest off Texas (Fig. 2). Slight deviations from this pattern were apparent in 1962 in two areas. Just west of the Mississippi River the flow was to the north and onshore, whereas off the south Texas coast there were indications of an inshore countercurrent to the north.

Current velocities ranged from a low of 4 km/day to a high of 14 km/day. Greatest velocities (9-14 km/day) were observed in waters over the central portion of the study area, i.e., off western Louisiana and eastern Texas. Lowest velocities occurred just west of the Mississippi River (5 km/day) and off south Texas (4 km/day) in the vicinity of Brownsville.

Table 2.—Comparison by cruise of recovery of ballasted and unballasted drift bottles within 30 days after release in the Gulf of Mexico

Cruise	Recoveries			Ballasted/ Total Recovered
	Ballasted	Unballasted	Total	
1-62	8	29	37	22
2-62	27	53	80	34
3-62	17	55	72	24
4-62	9	28	37	24
5-62	21	36	57	37
6-62	7	24	31	23
7-62	19	52	71	27
8-62	7	14	21	33
9-62	50	43	93	54
10-62	9	22	31	29
1-63	9	9	18	50
2-63	17	17	34	50
3-63	31	51	82	38
4-63	25	45	70	36
5-63	33	45	78	42
6-63	25	31	56	45
7-63	0	2	2	0
8-63	3	12	15	20
9-63	34	11	45	76
10-63	8	5	13	62
11-63	7	3	10	70
Totals	366	587	953	38

Table 3.—Comparison of the direction and speed of ballasted (B) and unballasted (U) bottles recovered within 15 days after release in the Gulf of Mexico.

Test	Type Bottle	Number Recovered	Direction (True)		Speed (km/day)	
			Range	Average	Range	Average
#1	B	4	—	276°	—	4.6
	U	6	230°-276°	268°	1.9-4.6	4.1
#2	B	4	007°-016°	013°	3.7-18.5	9.3
	U	5	347°-007°	357°	3.7-15.7	11.7
#3	B	6	244°-359°	263°	0.9-3.9	1.7
	U	6	—	244°	—	1.1
#4	B	6	204°-215°	207°	17.0-21.1	19.8
	U	2	204°-205°	204°	18.3-19.1	18.7
#5	B	5	—	339°	5.9-6.3	6.1
	U	4	331°-339°	334°	2.6-6.3	3.7
#6	B	5	292°-307°	302°	2.4-4.8	4.3
	U	6	292°-317°	305°	2.9-9.3	5.0
#7	B	3	—	298°	—	6.3
	U	5	—	298°	6.3-8.3	7.0
#8	B	5	180°-195°	187°	5.6-6.5	6.1
	U	5	195°-009°	334°	5.6-26.8	10.7
#9	B	4	—	291°	25.9-38.9	32.4
	U	3	—	291°	5.9-38.9	20.0
#10	B	3	336°-354°	346°	4.4-7.9	6.7
	U	4	341°-012°	360°	8.3-14.6	9.8

Resultant wind vectors for the cruise periods revealed differences between areas in the northwestern Gulf as well as differences between months. In January 1963, winds at New Orleans were generally northerly or offshore, those at Galveston northeasterly or alongshore, and those at Brownsville southeasterly or onshore. This circulation pattern of winds may account for the absence of recoveries of bottles released east of Galveston.

In February 1962 and 1963 winds were generally similar over the entire study area, i.e., east to southeast flowing west alongshore at New Orleans and Galveston and onshore at Brownsville. Strongest winds occurred at Brownsville in both years and probably accounted for the reduced rate of alongshore flow of surface waters observed in that area.

March-May.—Drift bottle movements indicated a transitional period for surface currents in the study area during both years with several distinct features (Figs. 3, 4). First, the flow of surface waters off Louisiana was predominately to the west in March of both years, but as time progressed, the flow direction generally shifted to the north and became onshore in May. This onshore component was more pronounced in May 1962 than in May 1963 when some east to west movement was still apparent. Apparent monthly differences in the timing of the breakdown of the dominant east to west movement between years may be accounted for by the difference in cruise dates between years or may reflect real yearly dif-

ferences. Associated with this dominant flow off Louisiana was a generally weak northward onshore movement of nearshore waters just west of the Mississippi River.

The second prominent feature during this period was the movement of waters off the south Texas coast. Recoveries during both years indicated an area of convergence of currents. Furthermore, as the season progressed, this arc of convergence moved northward up the Texas coast until the flow of surface waters became almost directly onshore. In May 1963, however, this pattern can only be inferred due to the paucity of drift bottle releases off the south Texas coast.

The third distinct feature of the circulation pattern was the indication of the presence of an oceanic surface current that existed in waters beyond the continental shelf. This was particularly apparent in March of both years and April 1962 when several bottles deposited on the edge of the shelf apparently moved against (straight line trajectory) prevailing shelf currents. From this set of data, it appeared that in the surface waters three current systems may have been present in the study area: a nearshore countercurrent, a shelf current, and an oceanic current.

Current velocities varied depending on location within the study area. Speeds of the dominant east to west drift off Louisiana ranged between 7 and 14 km/day whereas the weak onshore current just west of the Mississippi River ranged from 1 to 3 km/day. Within the area of convergence off Texas, speeds ranged from 3 to 17 km/

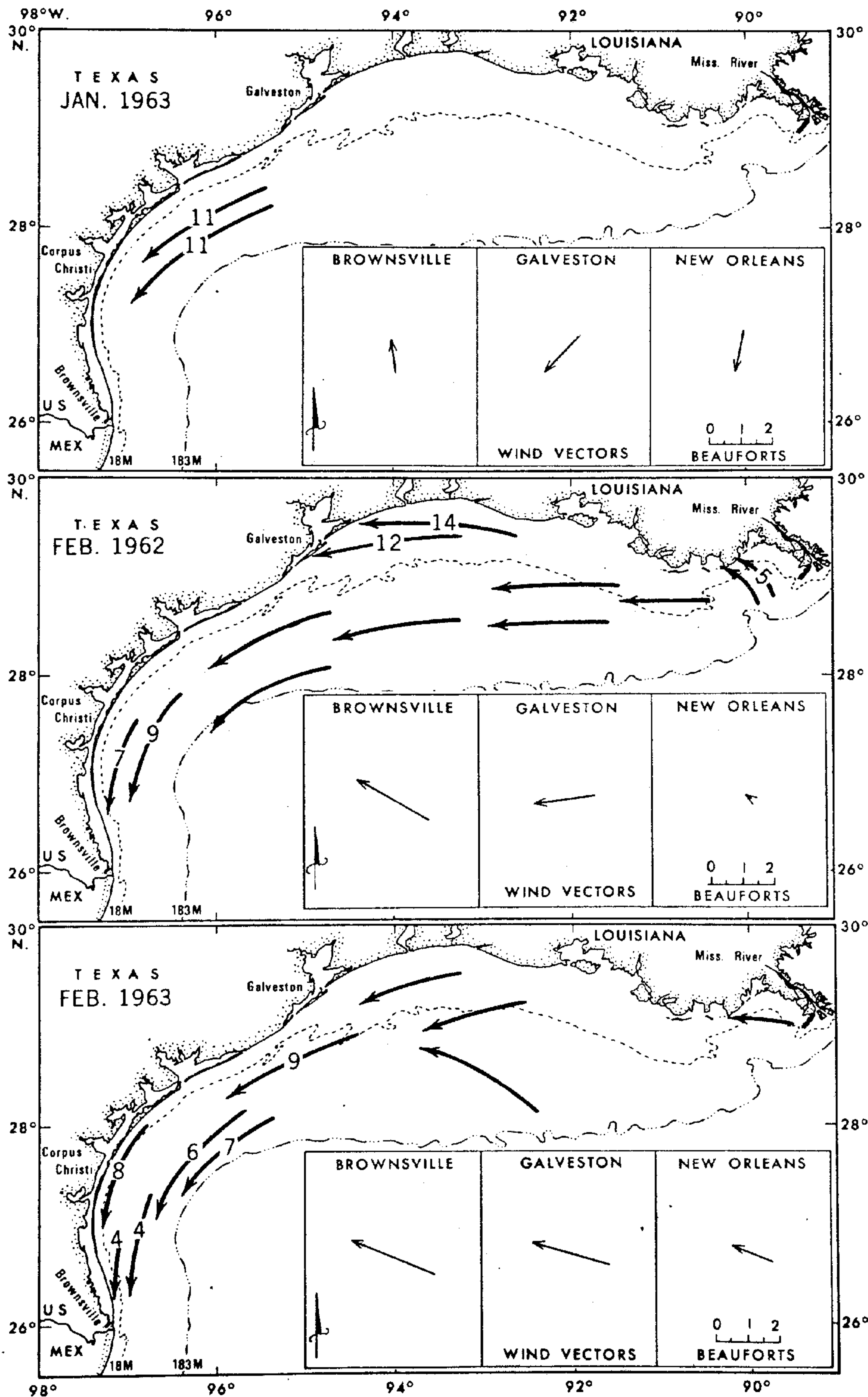


Figure 2.—Surface circulation deduced from recoveries of drift bottles released in January 1963 and February 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

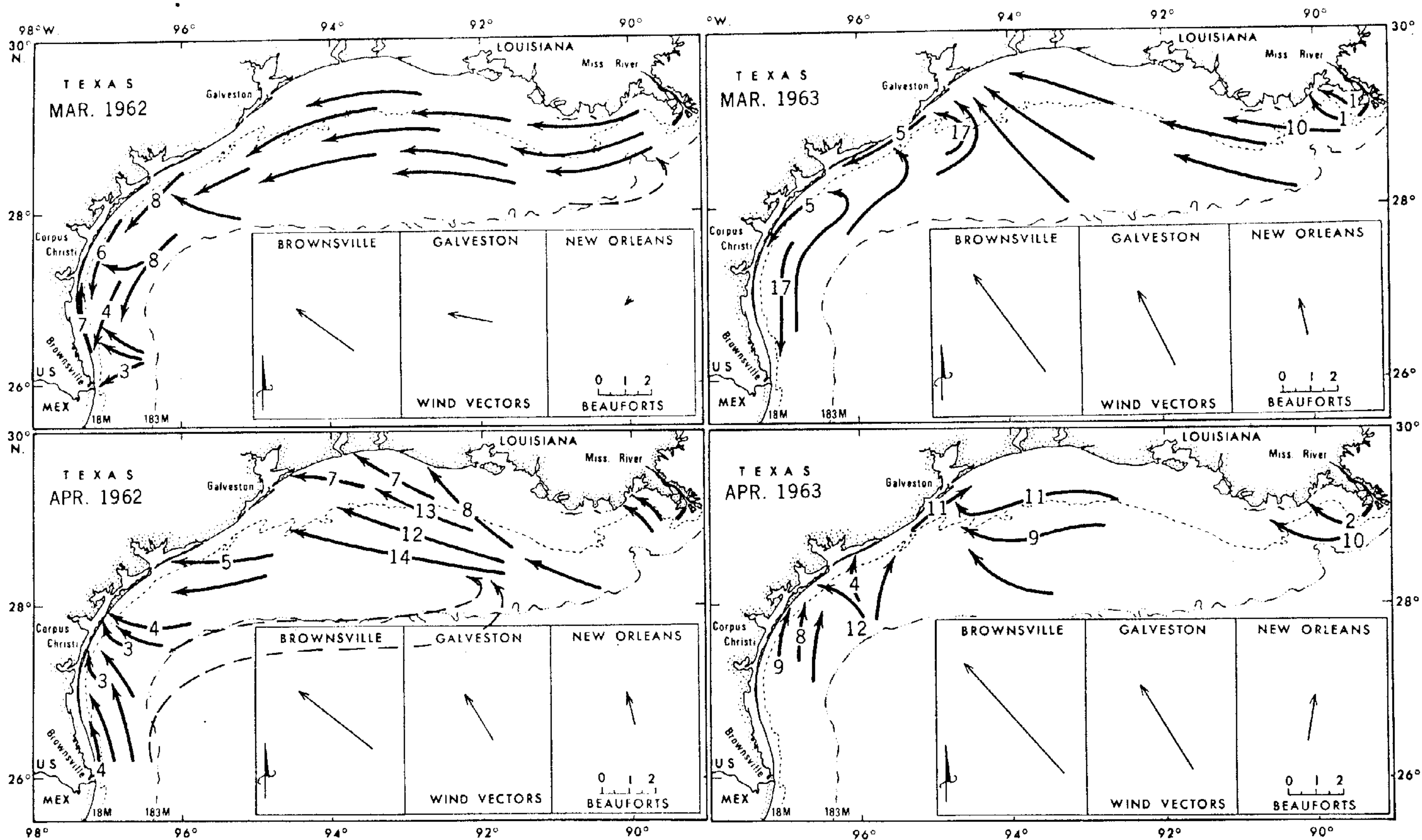


Figure 3.—Surface circulation deduced from recoveries of drift bottles released in March and April 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

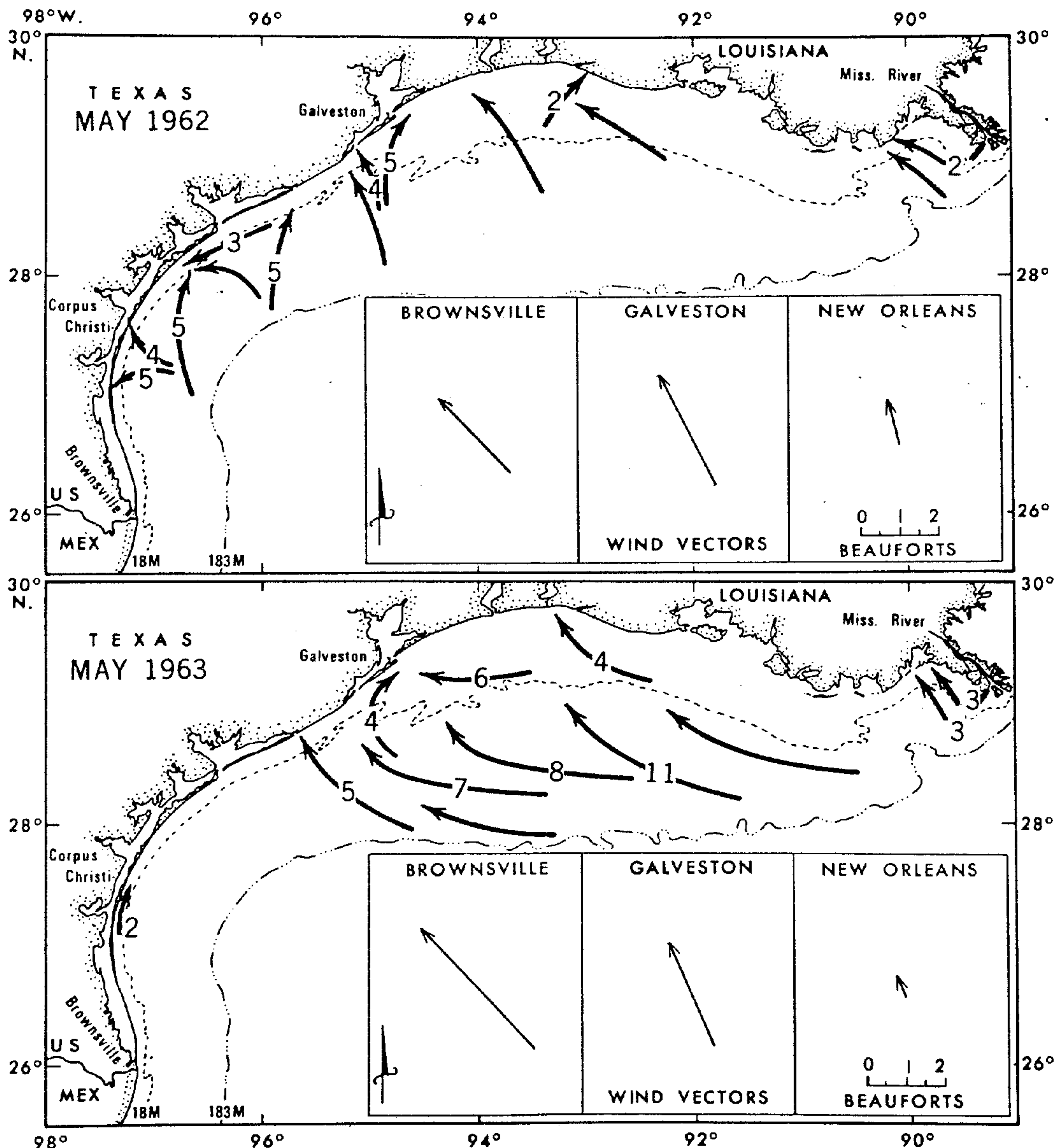


Figure 4.—Surface circulation deduced from recoveries of drift bottles released in May 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

day with an overall average of about 6. In general velocities of surface currents decreased from March to May as currents became more onshore.

With few exceptions, winds were generally similar between years over the study area, but a marked seasonal shift in direction was apparent. Resultant wind vectors indicated that the winds became more southerly or onshore during this 3-mo period and may account for the general weakening of the east to west flow of surface

waters off Louisiana and east Texas as well as a shift in surface currents to the north off south Texas. With the exception of May 1962, wind force was greatest at Brownsville.

June-July.—Following the March-April transitional period, the dominant east to west flow of January-February had in essence reversed (Fig. 5). Currents flowed northward along the south Texas coast, whereas

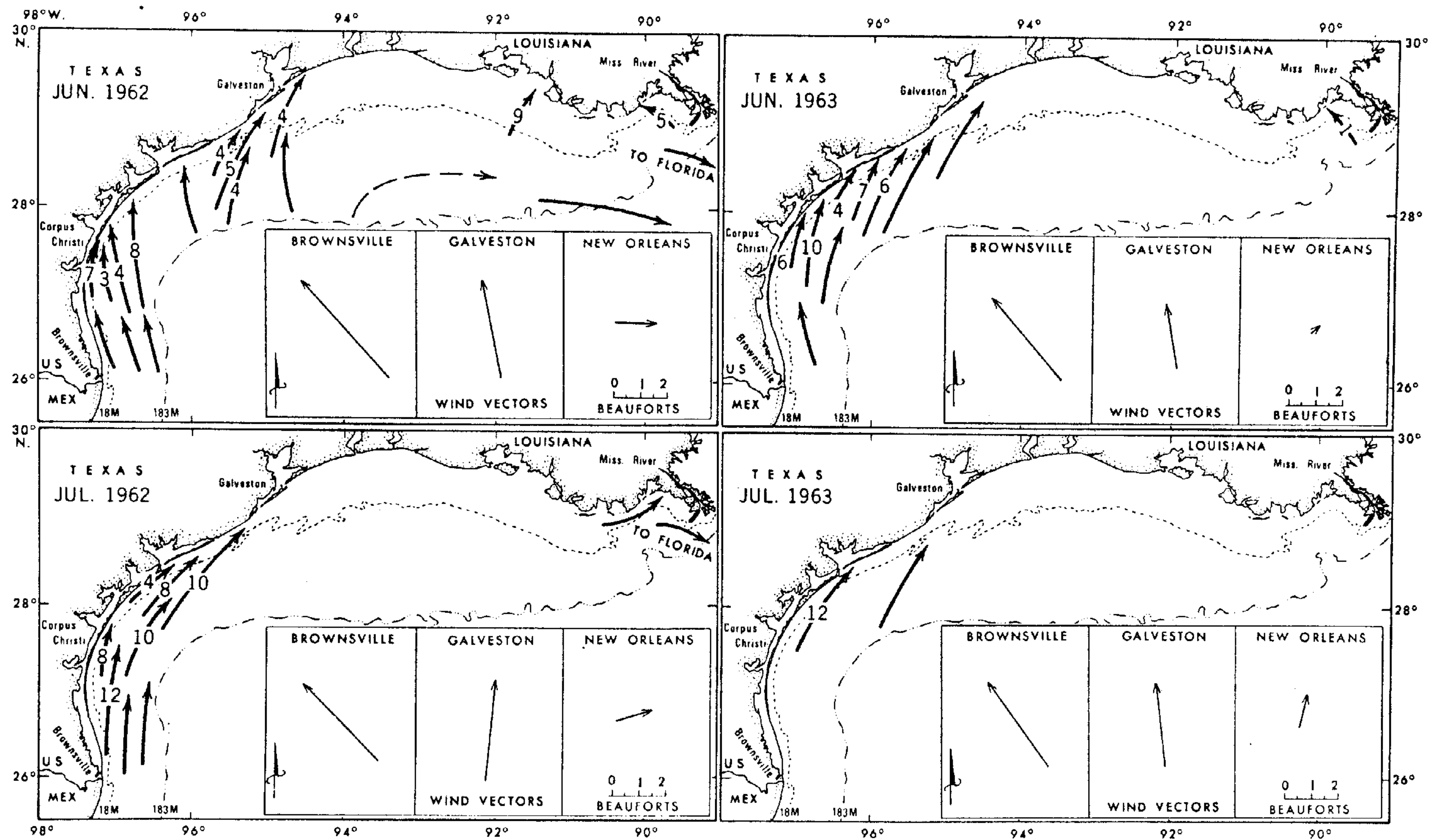


Figure 5.—Surface circulation deduced from recoveries of drift bottles released in June and July 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

off Louisiana currents were to the north or east with the northerly current generally restricted to nearshore waters and the eastward movement restricted to the deeper waters over the shelf. The strength of this eastward flow was apparently greater in 1962 than in 1963 as evidenced by the recovery of bottles as far away as Florida within 30 days after release. In 1963, bottles were also recovered in Florida but time adrift exceeded 30 days and the recoveries therefore are not shown in Figure 5.

Current velocities varied throughout the study area with values ranging from 3 to 12 km/day along the Texas coast and averaging 7 km/day. Onshore currents along the Louisiana coast ranged from 1 to 9 km/day with an average of 3 km/day. Monthly velocities were similar between years.

The influence of the prevailing southerly wind so characteristic of the summer in the northwestern Gulf of Mexico was readily apparent at Brownsville and Galveston for June and July of both years. Surface water currents off Texas were observed flowing either directly downwind or slightly to the right of the prevailing wind direction. Off Louisiana, however, the wind direction varied between years. In 1962, air flow was to the east whereas in 1963 it was more to the north. This variation generally supports the stronger eastward movement of surface waters off Louisiana in 1962.

August.—Drift bottles were released during this time period only in 1963, and their movements indicated still another transitional period in current direction and

velocity (Fig. 6). Surface currents, rather than moving alongshore and to the north, had shifted to onshore toward the west; velocities had slowed to a rate of 2-3 km/day, a marked decrease from those velocities observed in the June-July period.

At Brownsville and Galveston winds were generally southeasterly. At New Orleans, winds were variable, as evidenced by the relatively small resultant vector, and were northwesterly.

September-December.—The release and recovery of drift bottles indicated that surface currents had returned to the dominant flow noted in January-February, i.e., a general west to southwesterly flow (Figs. 7, 8). Several features of the circulation pattern, however, should be noted. First, recoveries of bottles in the vicinity of Brownsville, Texas, in 1962 indicated a westerly onshore movement that dissipated as the season progressed.

Second, the onshore component of the prevailing southwest current was not as apparent in 1963 as in 1962. Few bottles released in the study area were recovered within 30 days, and of those that were, most were released at nearshore stations. Whether this was due to the lack of areal coverage or the total number of bottles released is not known, but the results were similar to those observed in December 1962 (Fig. 8), a period when a large number of bottles were released and areal coverage was extensive. This absence of recoveries may indicate either an along- or offshore movement of surface waters.

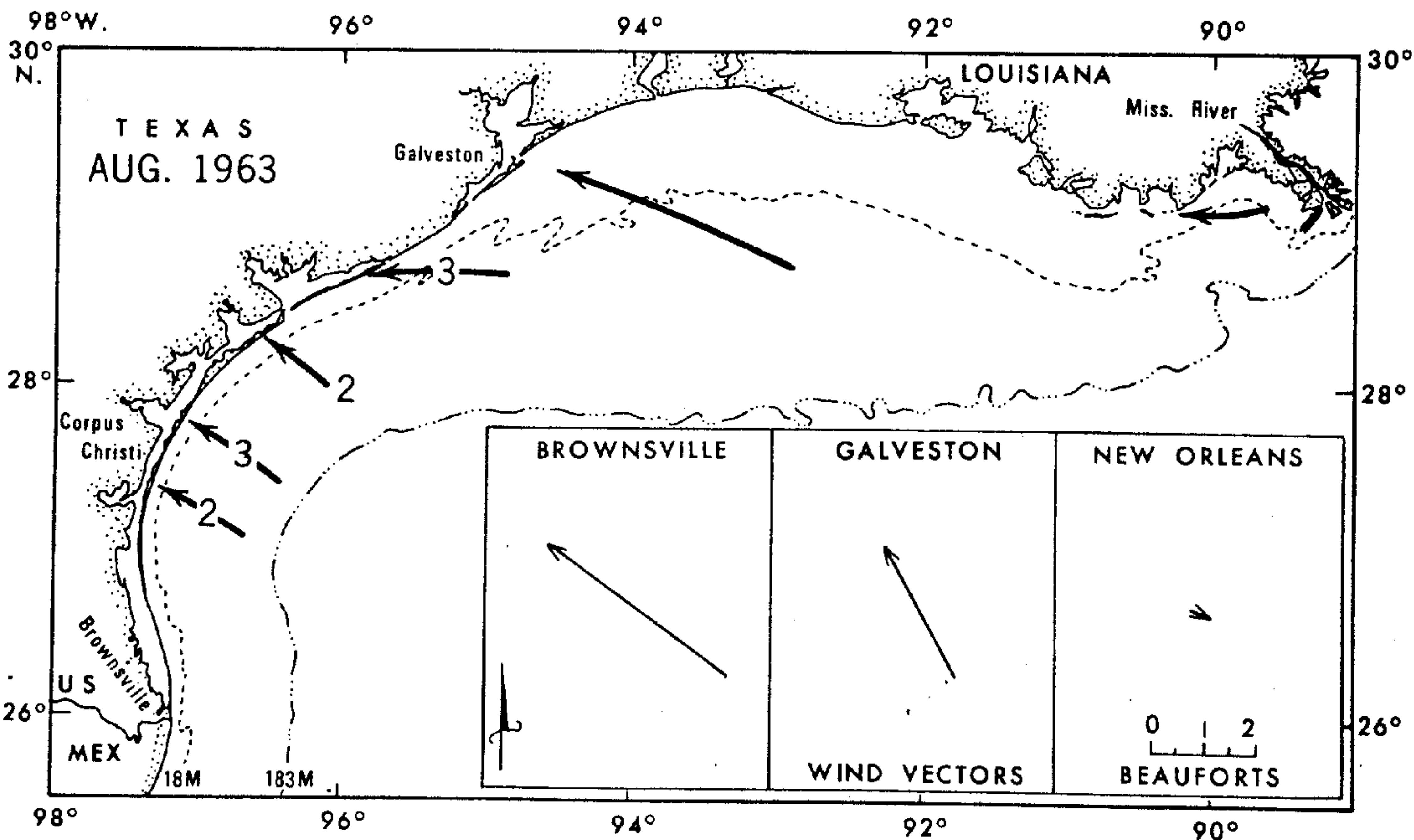


Figure 6.—Surface circulation deduced from recoveries of drift bottles released in August 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate average km/day).

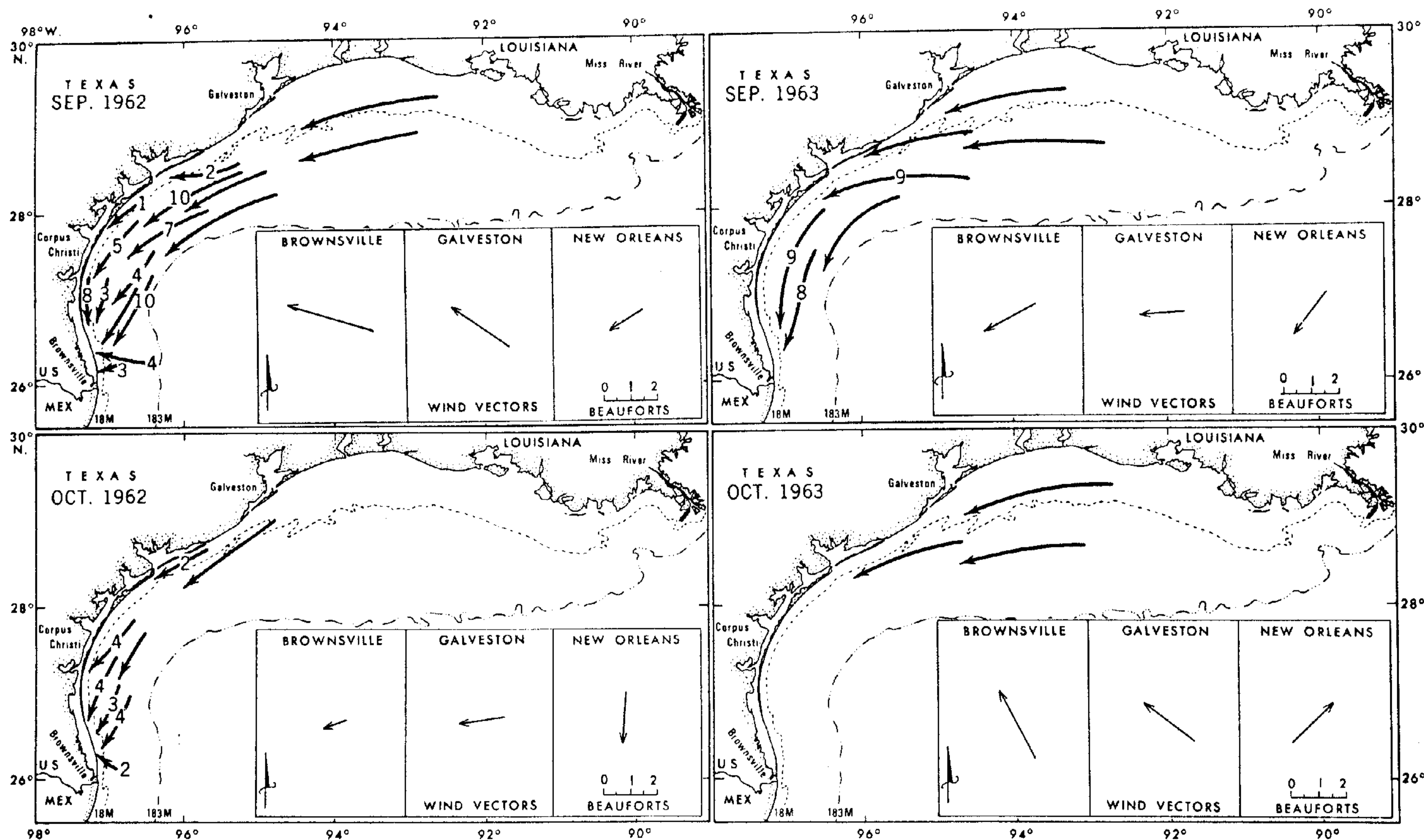


Figure 7.—Surface circulation deduced from recoveries of drift bottles released in September and October 1962 and 1963 in the northwestern Gulf of Mexico. (Arrows indicate direction of flow; numbers indicate a average km/day).

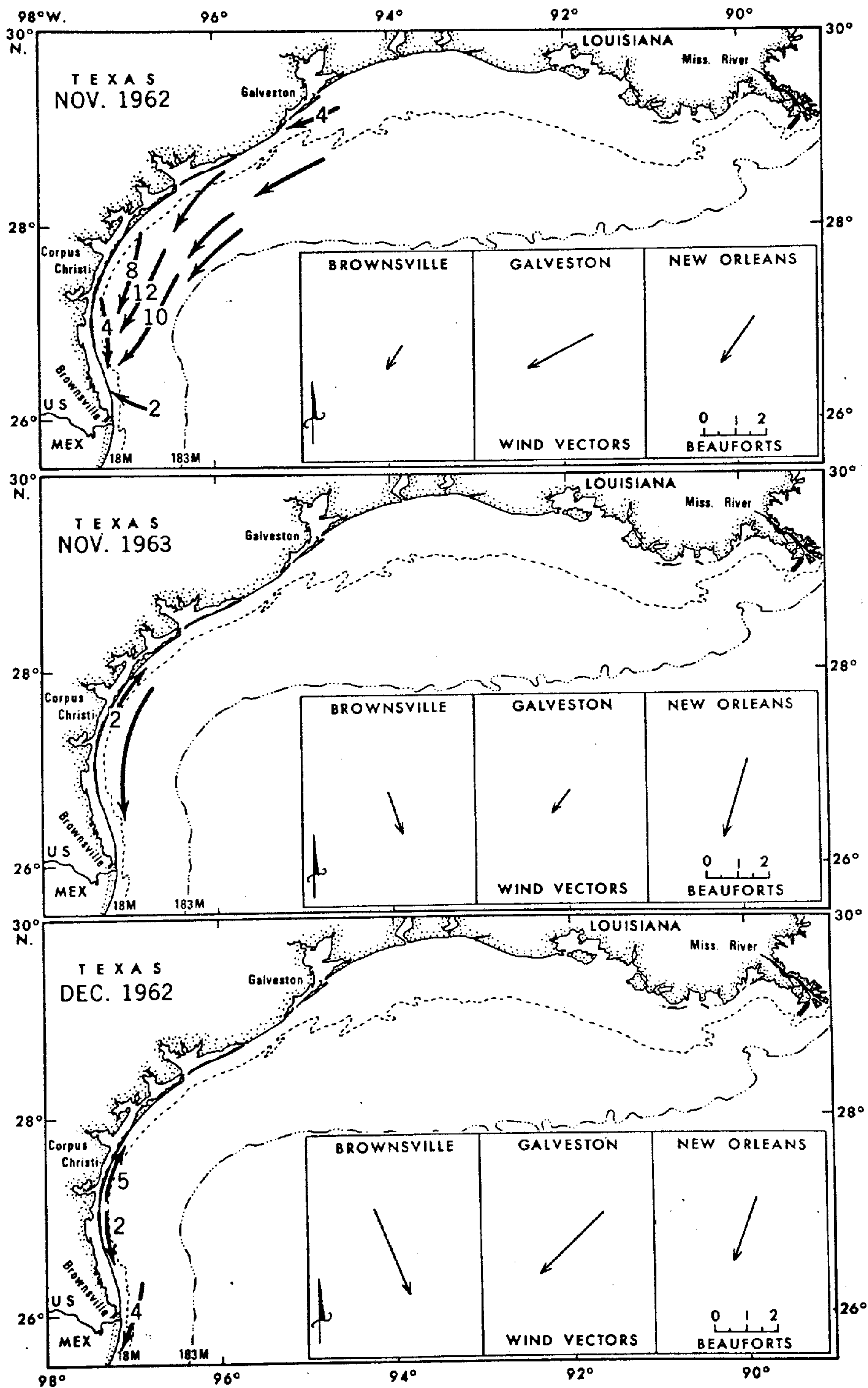


Figure 8.—Surface circulation deduced from recoveries of drift bottles released in November 1962 and 1963, and December 1962 in the northwestern Gulf of Mexico. Arrows indicate direction of flow; numbers indicate average km/day).

Table 4.—Estimated range and average current velocity for September-December 1962-63 in the northwestern Gulf of Mexico.

	1962		1963	
	Range	Average	Range	Average
September	1-10	5	8-9	9
October	2-4	3	no data	
November	2-12	7	no data	
December	2-5	3	no data	

Information on current velocities was generally restricted to the 1962 data, but no distinct trend was readily apparent. Ranges and averages for each month are shown in Table 4.

The seasonal shift in wind circulation over the study area during this period agreed generally with the direction of surface water movement. With few exceptions, east to southeast winds became more northerly until in November 1963 and December 1962 north winds dominated over the entire study area. The lack of drift bottle recoveries during this period supports the implied offshore southerly flow of surface waters.

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